

VIRTUAL SENSOR FOR DATA & SENSOR FUSIONCross-Reference to Related Applications

[000.5] This application claims the benefit of the priority date of Provisional Application No. 60/477,305, filed June 10, 2003.

Field of the Invention

[0001] This invention relates to fusion of information from sensors for the purpose of classifying objects or conditions observed by the sensors.

Background of the Invention

[0002] The use of sensors to determine the nature or classification of objects is old. Such sensors receive raw data from an observed direction or space in either a passive or active manner, and process the information according to some algorithm in order to make a determination of the nature of the object or condition. For example, a radar system operating as an active sensor may transmit radar signals in a desired direction, and then processes signals returned from a target to determine various characteristics of the received signal in order to characterize the target as, say, an F-15 fighter aircraft rather than a C-130 transport aircraft. A passive sensor might detect the emissions of an active sensor carried by a remote platform, determine the type of sensor detected, and identify platforms capable of carrying such an active sensor.

[0003] A great deal of work has been done in the field of fusion of the outputs of various sensors

associated with a battle region, in order to rationalize the results of the many sensors observing the region from different vantage points under different operating conditions.

5 [0004] Improved or alternative fusion is desired.

Summary of the Invention

[0005] A method according to an aspect of the invention is for fusing information from plural sources. 10 The method comprises the step of observing an object with at least first and second sensors, each of which (a) evaluates evidence or information and (b) based on the evidence, assigns a taxonomic classification to its observation of the object. The method further comprises 15 the step of fusing the evidence from the first and second sensors to produce compound evidence. A classification is assigned based on the compound evidence. In a particular embodiment of the invention, the classification based on compound evidence is taxonomic or type classification.

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Brief Description of the Drawing

[0006] FIGURE 1 is a simplified block diagram of a prior-art multiple-sensor fusion arrangement;

25 FIGURE 2 is a simplified block diagram of a prior-art sensor of FIGURE 1; showing how evidence provides the basis for taxonomic classification;

FIGURE 3 is a simplified block diagram of a sensor according to an aspect of the invention, showing that the evidence is available externally; and

30 FIGURE 4 illustrates a virtual sensor incorporating fused evidence from plural sensors, together

with a taxonomic classifier operating on the fused evidence to classify the target or object.

Description of the Invention

5 [0007] In FIGURE 1, a system 10 includes a first sensor 12, a second sensor 14, and a third sensor 16, each observing a region designated generally as 18 which happens, at the illustrated time, to contain an object 20. For definiteness, the region 18 may be considered to be a
10 region near a battlefield, object 20 may be an aircraft, and each of sensors 12, 14, and 16 may be any type of active or passive sensors used to detect and classify aircraft. The classification produced by sensor 1 is reported at an output port 12o, and is coupled by any
15 means, specifically as a hard-wired path 22, to a classification fusion function illustrated as a block 24. Similarly, sensors 14 and 16 each generate a classification or determination of the type of object at their output ports 14o and 16o, and these determinations are coupled to block 24 by any means, which in FIGURE 1 is illustrated as
20 a hard-wired path 26.
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[0008] In the prior-art arrangement of FIGURE 1, classification fusion arrangement 24 performs processing in known manner to rationalize the determinations made by the various sensors. As a simple example, if a large number of sensors report that object 20 is an F-16 aircraft, and one sensor reports that it is a battleship flying at altitude, block 24 may reject the battleship classification and produce a rationalized classification at its output port
30 24o to the effect that the object 20 is an F-16.

[0009] In FIGURE 2, exemplary sensor 12 is

illustrated as including a block 110 representing one or more transducers with their associated electronics. This might be, for example, the antenna, transmitter, and receiver of a radar system in the context of an active sensor, or a staring array and its amplifiers in the context of a heat sensor.

[0010] The signals representing raw information about the object sensed are applied from block 110 of FIGURE 2 to a block 112, which represents processing performed by the sensor on the raw data to generate information which allows classification of the type of object. This processing might be spectral processing of the received signal in the case of a radar system. The processing might also include decoding and information processing in the case of intercepted data or voice transmissions, shape estimation in the case of imaging sensors, kinematic information such as acceleration, and the like.

[0011] The evidentiary information produced by block 112 of FIGURE 2 is applied to a taxonomic (type) classification block 114, which makes a determination of the object type by comparing the evidence with stored information relating to the characteristics of the evidence for various types of objects. The final classification is output from port 120 for transmission over path 22.

[0012] In FIGURE 3, elements corresponding to those of FIGURE 2 are designated by like reference numerals. In FIGURE 3, a sensor 312 according to an aspect of the invention produces its taxonomic classification at an output port 3120, also includes a further output port 314 at which the evidence used by taxonomic classification

block 114 can be accessed.

[0013] In FIGURE 4, first, second, and third sensors 312₁, 312₂, and 312₃ are similar to sensor 312 of FIGURE 3. Each of the three sensors of FIGURE 4 observes object 20. In addition to producing three classifications at output ports 312_{o1}, 312_{o2}, and 312_{o3}, the externally available evidence from output ports 314₁, 314₂, and 314₃ is coupled by paths, illustrated as hard-wired paths 422 and 426 to an evidence fusion block 424. Evidence fusion block 424 produces fused evidence in any one of a variety of prior-art manners, to thereby effectively combine the evidence of sensors 312₁, 312₂, and 312₃, into the equivalent of a single virtual sensor processor 412. The combined evidence is presented to a taxonomic classification block 414, which can be in accordance with any prior-art arrangement, and more specifically may be similar to block 24 of FIGURE 1. Block 414 produces a taxonomic classification based on the combined evidence.

[0014] In general, the calculations are performed by letting $p(E|a)$ be the likelihood that a sensor produces evidence E when an object that the sensor observes has a characteristic a. A typical sensor will be able to produce more kinds of evidence E_n , $n = 1, 2, 3, \dots$ when an object with characteristic a is observed. Let $p(E_n|a)$ be the likelihood that a sensor will produce evidence E_n when an object observed by the sensor has a characteristic a. As a specific example, a sensor finds a dominant frequency of 100 KHz (kilohertz) when observing a J-100 aircraft engine, but may find a frequency of 120 KHz during the observation. The likelihood $p(100\text{ KHZ}|J-100)$ of observing 100 KHz may be 0.95, and the likelihood $p(120\text{ KHz}|J-100) = 0.05$. In

general, objects may have different characteristics a_k , $k = 1, 2, 3, \dots$. A sensor may produce the same evidence E_n when objects with different characteristics are observed.

Let $p(E_n|a_k)$ be the likelihood that a sensor will produce evidence E_n when an observed object has a characteristic a_k .

As an example, a sensor may find a dominant frequency of 100 KHz when observing a J-100 engine, but may find the same frequency when observing a J-150 engine. The likelihood $p(100 \text{ KHz}|J-100)$ of observing 100 KHz may be

0.95, while the likelihood $p(100 \text{ KHz}|J-150)$ may be 0.40 (the sums need not add to 1.00). Let $p_j(E_n|a_k)$ be the

likelihood that a sensor j produces evidence E_n when an observed object has a characteristic a_k . The invention

applies to any sensor, termed a "characterized" sensor, for which $p_j(E_n|a_k)$ is either known or can be estimated for one or more E_n and one or more a_k .

[0015] The classifications produced by sensors 312₁, 312₂, and 312₃ may be used for other purposes or not used, as desired.

[0016] Other embodiments of the invention will be apparent to those skilled in the art. For example, while hard-wired paths have been illustrated for coupling the evidence from each sensor to a combiner, the paths may be, or include, wireless portions, or be encoded, or in general of any appropriate sort.

[0017] Thus, in a very general aspect of the invention, a plurality of sensors observe an object, and the raw sensor data is processed to produce evidence signals representative of characteristics which may be used to classify the object as to type. The evidence from the plurality of sensors is fused to generate fused or combined

evidence. Thus, the fused evidence is equivalent to signals produced by a virtual sensor. The fused evidence is applied to a taxonomic classifier to determine the object type.

5 [0018] More particularly, a method according to an aspect of the invention is for fusing information from plural sources (312₁, 312₂, and 312₃). The method comprises the step of observing an object with at least first (312₁) and second (312₂) sensors, each of which (a) evaluates
10 evidence or information and (b) based on the evidence, assigns a taxonomic classification to its observation of the object. The method further comprises the step of fusing the evidence (block 424) from the first and second sensors to produce compound evidence. A classification is
15 assigned (block 414) based on the compound evidence. In a particular embodiment of the invention, the classification based on compound evidence is taxonomic or type classification.